

**Improving the Representation of Land in Climate Models
by Application of EOS Observations**

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**Summary of Research
Final Report
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Final Report for the NASA EOS/IDS Investigation: “Improving the representation of Land in Climate Models by Application of EOS Observations”

The PI's IDS current and previous investigation has focused on the applications of the land data toward the improvement of climate models. The previous IDS research identified the key factors limiting the accuracy of climate models to be the representation of albedos, land cover, fraction of landscape covered by vegetation, roughness lengths, surface skin temperature and canopy properties such as leaf area index (LAI) and average stomatal conductance. Therefore, we assembled a team uniquely situated to focus on these key variables and incorporate the remotely sensed measures of these variables into the next generation of climate models.

The current proposal activity has had two major directions:

- a) Development of data sets needed by climate models with Boston University scientists concerned with albedo, LAI, and land cover and University of Maryland scientists concerned with land cover fraction and skin temperature.
- b) Utilization of EOS data in climate models with the NCAR land group under Bonan, the University of Arizona group under Zeng and the University of Texas at Austin group under Yang.

Much of the earlier activity has involved the improvement of current land models to make better use of the data that is now becoming available and prototyping with AVHRR data. However, within the last three years, our team has been able to begin exploiting some of the highly valuable information coming from the Terra MODIS instrument for climate model improvement. In doing so, we have also demonstrated that such usage provides an additional level of quality filter to the data, since we have been able to raise questions about both the data algorithms and model algorithms. We highlight substantial progress made in four areas.

A. Land surface modeling

This IDS has made major fundamental contributions to the utilization of the new data from the Terra platform. One such contribution was the development of the next generation land model

referred to as the Common Land Model (CLM0) and Community Land Model (CLM2), especially tailored for use of such data.

1) A new land surface model, the “Common Land Model” (CLM0) has been developed based on the components from the PI’s old model BATS, Dr. Dai’s PhD dissertation model, IAP 94, and the NCAR LSM, in part for better utilization of satellite data. Dai’s article summarizing the model has been published in the Bulletin of AMS. The documentation for the code is located at <http://climate.eas.gatech.edu/dai/>.

2) The performance of the CLM when coupled to CCM3 was documented for two different versions, (CLM0 and CLM2) in Zeng et al. [2002] and Bonan et al. [2002], which show substantial improvements in several areas over LSM. Analyses of the latter pointed to additional issues to be addressed. An initial analysis of the issue of under canopy turbulent transports and a new parameterization for community use with CCSM was reported in Zeng et al. [2003b]. The significant biases in the simulation of ground temperature over arid and semi-arid regions in the NCAR CCSM2 have been improved.

3) Dai et al. [2004] further developed a modification of CLM that includes separate temperature calculations for sunlight and shaded leaves (only irradiated by diffuse light) and shows that this distinction can also significantly alter respiration and carbon fluxes.

4) Progress has also been made in the treatment of vertical soil heterogeneity (e.g. mass layers) in the land surface model [Schaudt and Morrill, 2002]. All the necessary theory has been finished for placement of the code into the CLM.

B. Developing EOS related data for climate model boundary conditions

All efforts in this direction focused on providing the data needed for CLM to be run as part of the CCM3 model as accurately as possible with the standard products from Terra observations and developing improved approaches that would suggest improvements needed over the standard products.

1) The BU LAI/FPAR team has developed two high quality (high spatial coverage, low uncertainties) time series products, namely monthly LAI and FPAR products at 1km and 4km resolutions. Temporal coverage of both data sets extends from Feb. 2000 through present. Data sets are available through FTP (<ftp://crsa.bu.edu/pub/rmyneni/myneniproductions/MODIS/>) both at 4-km and 1km resolution.

2) The BU land cover team created two datasets for use in the land model:

- a) Land cover – the standard IGBP land cover product. The land model was formulated for use in the mosaic structure in which CLM0 is implemented.
- b) Plant functional types (PFTs) – work with Bonan is directed toward making this an alternative standard boundary condition available to the CCSM community. It is preferred for coupling in ecological and biogeochemical processes. A 1km data layer depicting the seven primary PFT's used within the CLM2 was created.

The BU land cover team has also directed significant energy in developing methods to characterize continental and global scale vegetation phenology from MODIS [Zhang et al., 2003]. For this work, the annual cycle of vegetation phenology inferred from remote sensing is defined by four key transition dates: greenup, maturity, senescence, and dormancy. These dates identify the key phenological phases of vegetation dynamics at annual time scales.

3) The University of Maryland continuous field group has completed development of a global data set of percent tree cover, percent herbaceous and percent bare ground at 500m resolution based on an annual time series of MODIS data. In addition, Hansen et al. [2002b] completed analysis of time series of percent tree cover from 20-year 8km AVHRR data sets. The analysis finds where change in forest cover has occurred and indicates that the algorithm for estimating percent tree cover is appropriate for identifying change as multi-year time series of MODIS data becomes available.

4) Following the above three group's data development, a new generation land surface dataset at 0.5 degree resolution for use in CLM was created using the highest quality reprocessed MODIS products of LAI, PFTs and fraction of bare soil. Tian et al. [2004b] described how the data was created and showed the improvement for the surface albedo.

5) The BU MODIS albedo team has prepared appropriate global coarse resolution albedo data sets for use with the CLM at 0.05 degree (<http://duckwater.bu.edu/index.html>), 0.25 degree, 0.5 degree and 1 degree resolutions in a geographic projection. They also investigated the quality of MODIS albedo over snow-covered or partly snow-covered locations and found MODIS albedo values and tower measurements have a good agreement when the region around a tower is either completely snow covered, or completely snow-free [Jin et al., 2003]. This agreement breaks down when the area is only partially covered by ephemeral snow or by patches of melting snow in the fall and spring.

6) Zeng et al. [2003a] with the University of Arizona has successfully derived a global 8-km fractional vegetation cover (FVC) dataset from 1982-2000 using NOAA/NASA land pathfinder normalized difference vegetation index (NDVI) data. The data is now widely used by NASA and NCAR.

7) Accurate characterization of surface emissivity of vegetation, bare soil and their mixtures is essential to retrieve land surface skin temperature in remote sensing and to correctly participating net radiation into sensible and latent heat fluxes in modeling. By now, however, most of the land surface models assume the surface emissivity as constant. Jin and Liang [2003], with the University of Maryland converted MODIS spectral emissivities into GCM-required broadband emissivity. Analyzing the global emissivity data illustrates that emissivity is about 0.97-0.98 for densely vegetated areas ($LAI > 2$), 0.93-0.98 for sparse vegetation ($LAI < 2$), and 0.85 in April and 0.90 in November for bare soil like desert areas. Seasonality of emissivity is a reflection of emissivity dependence of underlying land vegetation and soil content. This finding changed the modeler's concept that emissivity is a constant value globally. Currently, we are driving a parameterization of such for use with CLM.

In addition, Jin [2003] created a long-term (1981-1998), monthly, global, 8km, land surface skin temperature diurnal cycle data set (LSTD) from AVHRR measurements to overcome the present only twice per day's data record. As a unique and independent resource, LSTD is valuable for studying the land surface climate and for evaluation model performance.

C. Remote sensing data and model simulation comparison

Specific land climate models differ somewhat from each other in both the details of the process descriptions and the numbers used to quantify these descriptions. However, by comparing one or more particular models with the satellite measured variables, we can uncover what the most crucial model parameters and parameterizations are and where the observed data may be questionable.

An early such study, Wei et al. [2001], compared AVHRR derived albedos with a simulation of the NCAR CCM3 with its previous land model, LSM. Over the last 3 years we have gained considerable insight into potential improvements of land models and some of the MODIS algorithms by careful comparisons of MODIS albedos and LAI/FPAR products with equivalent fields generated by the CLM0 and CLM2. Some of the notable findings in comparing with MODIS products are:

1) Albedo

Model and MODIS data are in relatively good agreement for dense vegetation canopies, however, some fine tuning of model parameters may be warranted [Zhou et al., 2003a]. The largest discrepancies between model and satellite inferred albedos are in arid/semi-arid lands [Tsvetsinskaya et al, 2002; Zhou et al., 2003a; Tian et al., 2004b; Wang et al., 2004], and mixtures of snow and vegetation [Jin et al, 2002; Zhou et al., 2003a].

Work at GaTech with CLM0 has uncovered different issues about snow with vegetation than that with work at UTA with CLM2. In CLM0/CCM3 model [Zhou et al., 2003a], the model has a low bias relative to MODIS. For shrub cover, this appears to be an artifact of the prescription of stem area index (SAI) – values appear to be too high or misused by assumption of homogeneity with

the leaves in the land model. Over many grid-squares with needleleaf evergreen trees, model LAI too high appears to be the main problem. By contrast, CLM2/CCM3 [Niu and Yang, 2003] appears to have excessive albedos for canopies in the presence of snow, apparently an artifact of an assumption of snow interception that was not in CCM0.

In a more recent study, Tian et al. [2004b] replaced the old land surface data created from AVHRR data in CLM2/CCM3 with a new land surface dataset created from MODIS products, and assessed how inaccuracies in the land surface data used in CLM2 contribute to the model albedo biases. The results indicated that most of the positive albedo biases result from an underestimation of LAI or an overestimation of the grass/crop fraction in the old land surface data. In addition, albedo bias for grass/crop is bigger than that of trees, which points to the possible problem of two-stream model in CLM2 in simulation of grass/crop albedos.

A more thorough study conducted by Wang et al. [2004] systematically compared the MODIS albedo with the CLM2/CCM3 output, and the MODIS BRDF with the two-stream method for radiative transfer through canopy as used in CLM2, and provided a good starting point towards the development of a BRDF-based treatment of radiative transfer model in the next generation of regional and global model.

2) LAI/FPAR

The paper by Tian et al. [2004a] examines a full seasonal cycle of LAI and FPAR and emphasizes the large discrepancies between model and MODIS seen for late winter conditions and the major improvements provided by MODIS relative to earlier uses of AVHRR data to provide model fields. This study has especially highlighted the role of SAI used by land modelers to represent the effects of non-green canopy surfaces such as stems and dead leaves.

D. Application of EOS related data in land surface models and climate change study

1) Albedo

The studies of Tsvetsinkaya et al. [2002] indicate that the largest spatial variations of MODIS albedo are within arid systems where the previously poorly characterized albedos of mineral

surfaces are important. A further draft manuscript by Tsvetsinkaya et al. [2003] indicates a more global analysis of the arid systems. Such systems have a much wider range of albedos than has been realized by modelers. We have shown that these can be closely related to previous maps of the surface mineral composition, i.e., maps of soils and rock cover, which can be specified as boundary conditions by climate modelers. The result also was described in the News and Views section of Nature [Lincoln, 2002].

2) Emissivity

Analyzes of Zhou et al. [2003b] about relations among MODIS surface albedos, ASTER broadband (3–14 μm) emissivities in North Africa demonstrate that emissivity over bare soil exhibits statistically significant correlations with albedos at both broadbands and most of spectral bands, and decreases linearly with albedos. This study provides guidance for the possible inclusion of such correlation to specify albedo and emissivity in climate models and improve their boundary conditions.

A follow-up paper by Zhou et al. [2003c] finds that soil emissivity in current models is too high compared with ASTER data over Northern Africa and the Arabian Peninsula. When a more realistic emissivity value is used, the model cold bias over the Sahara in comparison with land surface air temperature observations could be partially reduced. Sensitivity tests based on CLM2/CCM3 indicate that there is a linear relationship between changes in emissivity and changes in temperature. On an average for the study region, a decrease of soil emissivity by 0.1 will increase ground and air temperature by about 1.1°C and 0.8°C, respectively. The temperature increases are slightly higher in winter than in summer and twice as large during nighttime as during daytime. This study highlights the importance of the accurate emissivity used in the land models.

3) Skin temperature

Accurate measurements of surface radiative temperature, i.e. land surface skin temperature (LST), would be more directly interpretable in terms of the surface response to increase of greenhouse gases than the more conventional screen temperatures. Such measurements have not previously been attempted because of the difficulties of converting existing observations into a

meaningful measurement. Jin and Dickinson [2002] have developed procedures for removing the effects of changing satellite orbits and cloud contamination from skin temperatures estimated from AVHRR channels 4 and 5, and provided a first estimate of the trends of land surface skin temperature over the last two decades. The estimated land temperature increase ($0.43 \pm 0.2^{\circ}\text{C}$ per decade) is not only much greater than that for the atmosphere but apparently somewhat larger than the estimates of surface air temperature increase from in situ measurement.

4) Human impacts on urban climate

Considering 75% of the people in the USA and Europe are living in urban areas, accurately simulating and predicting weather and climate over urban areas is extremely important. Jin et al. [2004] identify how human urban areas modify the climate systems by using MODIS measurements. The diurnal, seasonal, global, high resolution MODIS data illustrate that urban areas, in general, increase surface skin temperature by 1-5 degree, decrease surface albedo by about 15%, decrease surface emissivity by 2%, and cause increases of aerosol and clouds optical depth. Analyzing urban pixels globally discloses the ranges and extremes of urbanization effects and identifies what parameters are important in modeling urbanization. Currently, we are spearheading the application of MODIS measured urban characterization to improve climate model treatments of this component.

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